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**6. AUTHOR(S)**
Charles G. Sammis[1], Ronald L. Biegel[1], and Ares J. Rosakis[2]

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
University of Southern California (LA)
837 West Downey Way
Los Angeles, CA 90089-1147

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Air Force Research Laboratory
29 Randolph Road
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High-speed digital photography was used to observe the generation of S waves by explosions in fracture-damaged photoelastic Homalite plates. We found that either a preferred orientation of the pre-existing fractures or an anisotropic initial stress field produced significant S wave radiation in the far field. These experimental observations support theoretical predictions by Johnson and Sammis (2001).

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# AN EXPERIMENTAL STUDY OF S WAVE GENERATION BY FRACTURE DAMAGE IN UNDERGROUND NUCLEAR EXPLOSIONS

Charles G. Sammis[1], Ronald L. Biegel[1], and Ares J. Rosakis[2]

University of Southern California[1] and California Institute of Technology[2]

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High-speed digital photography was used to observe the generation of S waves by explosions in fracture-damaged photoelastic Homalite plates. We found that either a preferred orientation of the pre-existing fractures or an anisotropic initial stress field produced significant S wave radiation in the far field. These experimental observations support theoretical predictions by Johnson and Sammis (2001).

## OBJECTIVES

The overall objective of this research program has been to understand and quantify the extent of fracture damage in the non-linear source region of an underground nuclear explosion and to assess its effect on the radiation of seismic energy to the far field. Of particular interest is the generation of high-frequency shear waves that may affect regional discrimination and yield estimation. The specific objective of this year's research has been to develop experimental techniques in Professor Ares Rosakis' high-speed digital photography laboratory at Caltech to directly observe the generation of S waves by fracture damage in photoelastic samples. We wish to explore the effects of the initial shear stress and the initial fracture density (damage) on the amplitude of the S-wave radiation.

## RESEARCH ACCOMPLISHED

The experimental apparatus shown in Figures 1 and 2 was developed by Xia et al. (2004) to observed a dynamic rupture on a fault plane in a 10-cm-square 1-cm-thick plate of Homalite, which is a transparent photoelastic polymer. When observed in transmitted polarized light as in Figures 1 and 2, gradients in shear stress can be measured.

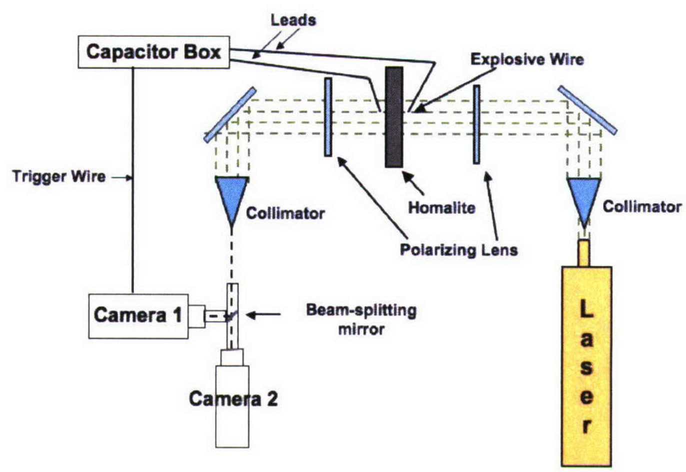


**Figure 1. Schematic of experimental apparatus used to image dynamic ruptures in photoelastic plates. A high-voltage pulse is applied to a wire through the sample which explodes to reduce the normal stress on a –cm-long patch, thereby nucleating a bilateral rupture on the fault plane. The voltage pulse also starts the high-speed digital camera.**

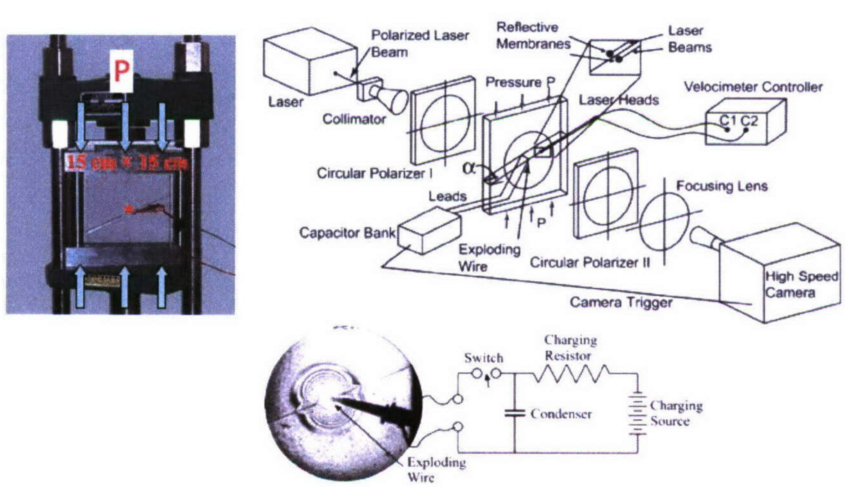


**Figure 2. Experimental configuration showing uniaxial loading frame and nucleation circuit.**

Figure 3 shows a damaged sample from the study by Biegel et al. (2008), in which we demonstrated that off-fault damage significantly reduces the rupture speed. The fracture damage was produced by scoring a grid onto both sides of the homalite sample with a razor knife and then dipping the sample into liquid nitrogen. The thermal shock produced a network of fractures which nucleate from the grid of scratches.

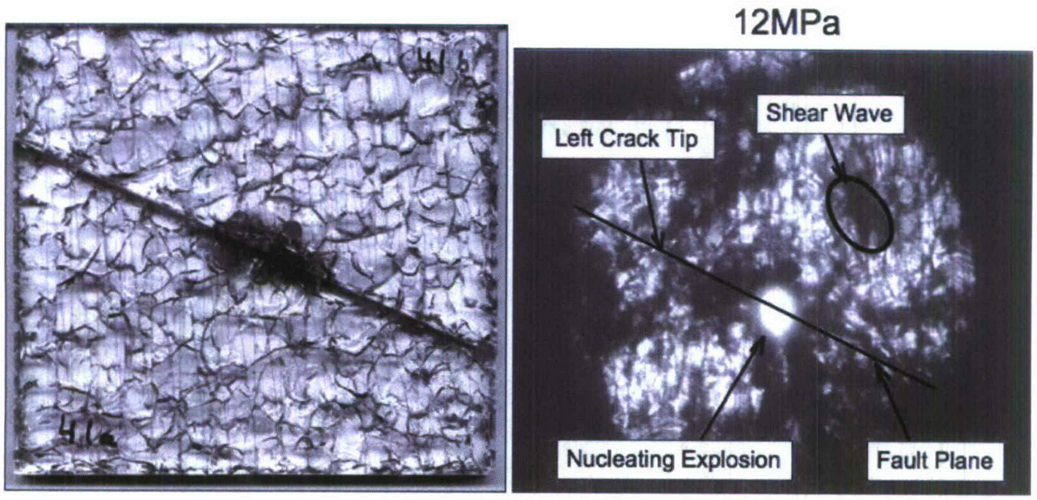


**Figure 3. Fracture damaged homalite plate from Biegel et al. (2008).**

In the present study, we drilled a hole in the center of the sample (with no fault plane) and scored a circular region centered on the hole, as shown in Figure 4. A hole was drilled in the center of the damaged region for the exploding wire.

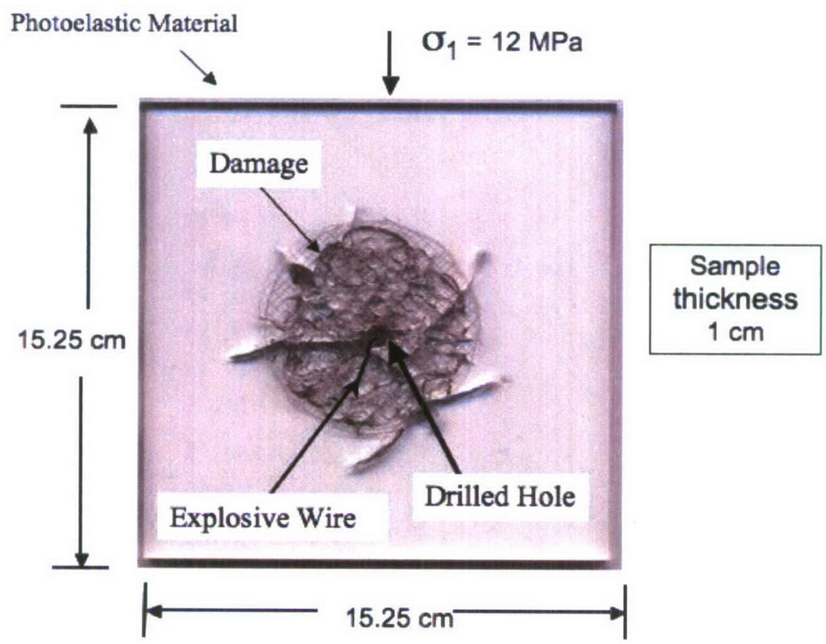


**Figure 4. Homalite plate with circular region of fracture damage.**

As illustrated in Figure 5, an explosion in the center of the damaged circle produced strong S waves.

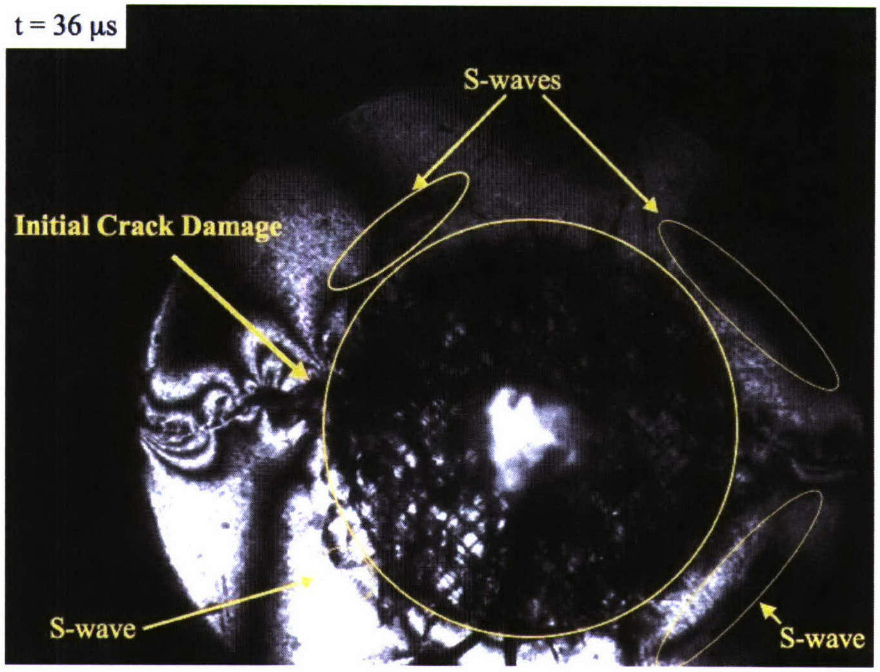


**Figure 5. Frame at 36 μs after the explosion from the high-speed digital movie using the sample in Figure 4.**

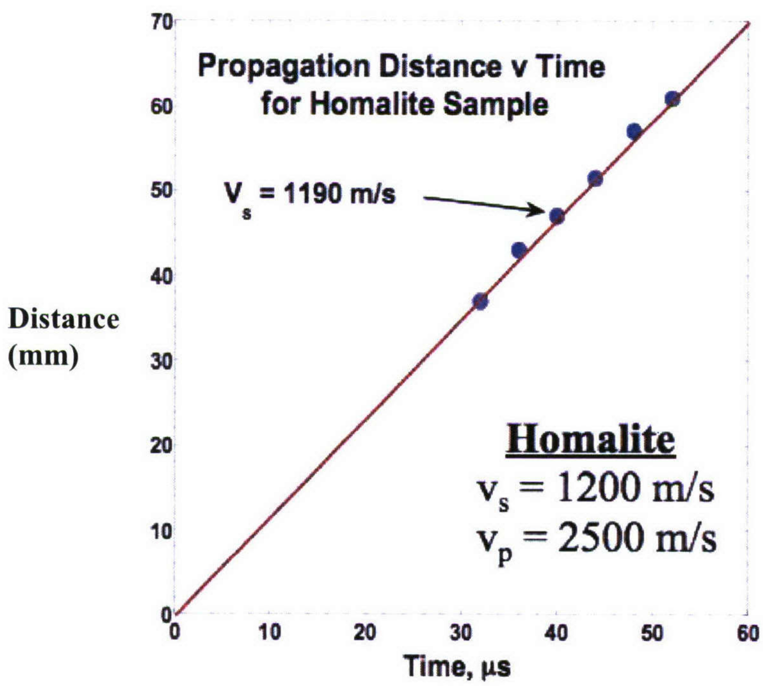


**Figure 6. Propagation distance of the S wave in the undamaged Homalite outside the damage zone as a function of time verifying that it is moving with the known S wave velocity in Homalite (1200 m/s).**

The only problem is that an explosion in an undamaged plate under uniaxial loading also produces S waves, as illustrated in the numerical simulation in Figure 7. However, we were able to show that S waves generated in a damaged circle were stronger than those generated in an undamaged plate at the same load, and additionally that S waves are also generated in a plate with oriented damage in the absence of a uniaxial load.

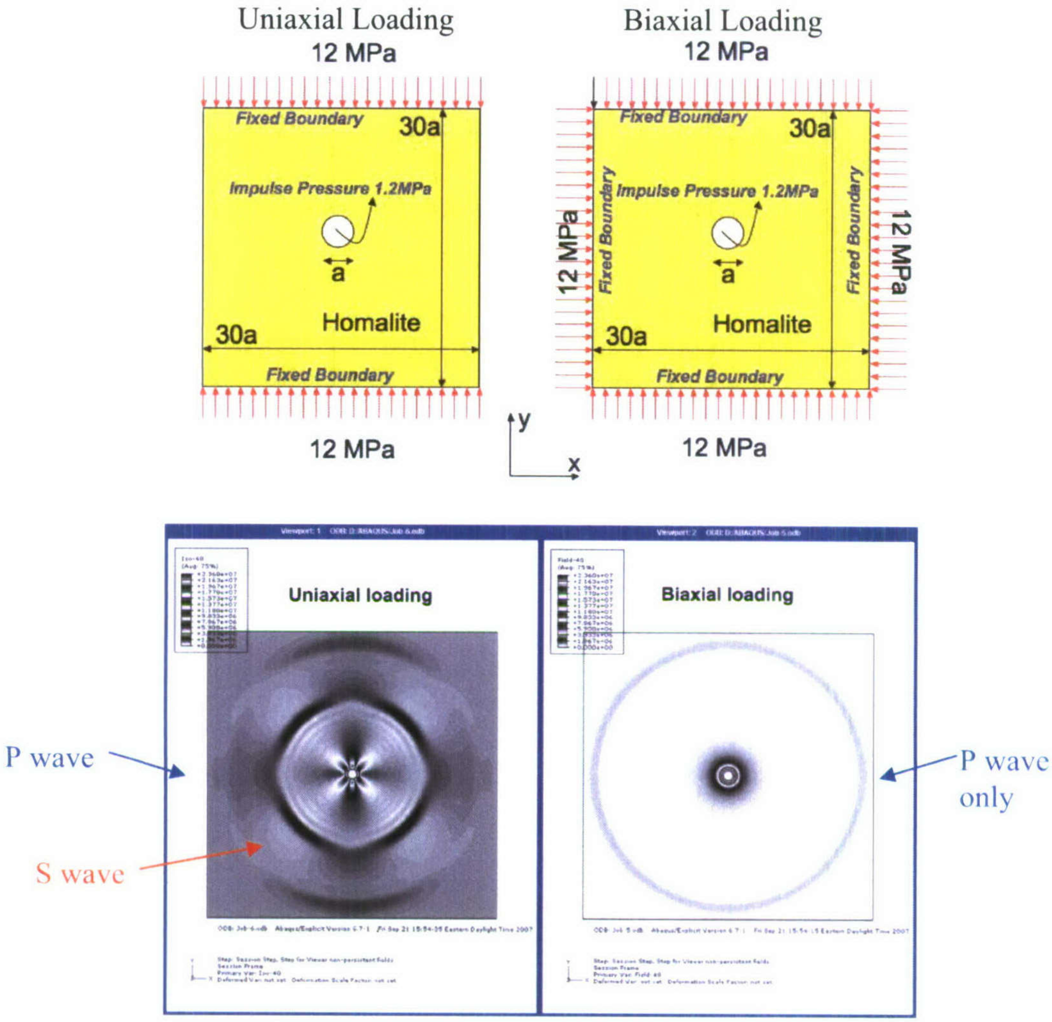


**Figure 7. Numerical simulation of an explosion under condition of uniaxial and biaxial loading. S waves are generated in the uniaxial case even in the absence of damage.**

## CONCLUSIONS AND RECOMMENDATIONS

Our main conclusion is that oriented damage in the source region of an explosion makes a strong contribution to the generation of S waves in the far field of an underground explosion as predicted by the theoretical calculations of Johnson and Sammis (2001). We are currently conducting experiments to quantify the enhancement in S-wave generation associated with damage in the non-linear regime of an underground explosion.

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